Geostationary Imaging Fabry-Perot Spectrometer (GIFS)

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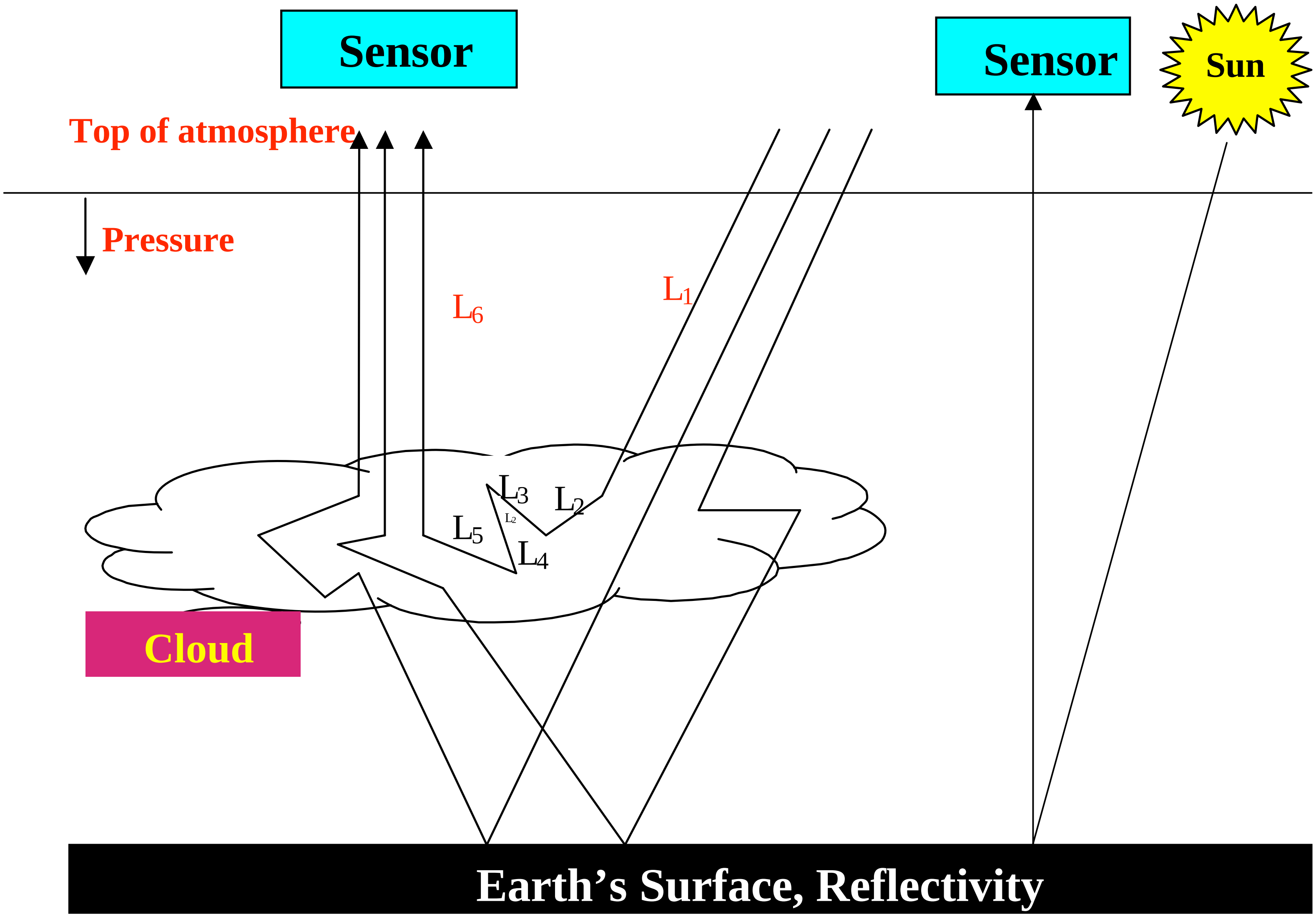
GIFS Instrument

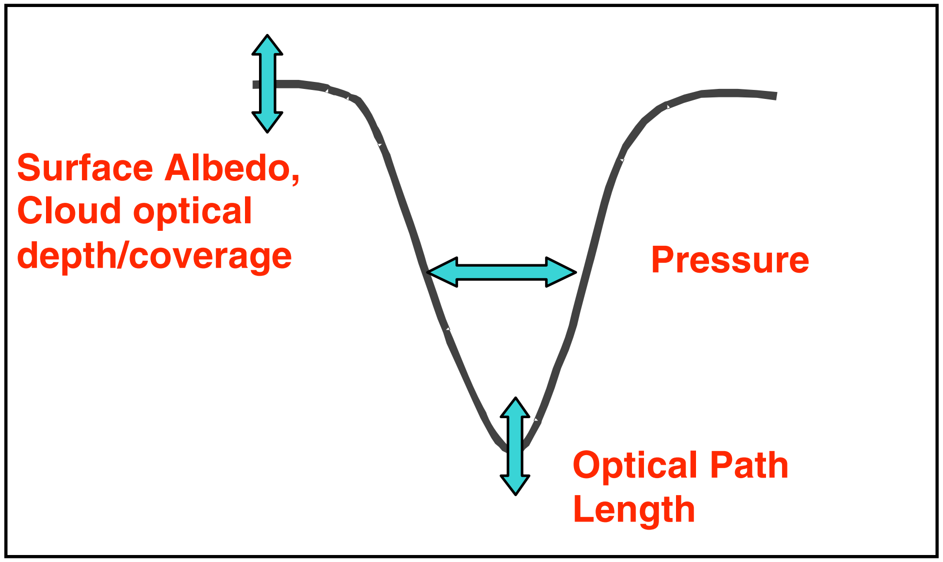
- GIFS is a tunable imaging triple-etalon Fabry–Perot Interferometer (FPI) to be deployed on a geostationary satellite to obtain high-spatial resolution 2-D measurements of spectral line shapes in the backscatter solar radiation.
- The unique features of the GIFS instrument are its
  - Tunability- spectral
  - Imaging capability – spatial

  => Use it as a tunable filter

Solar Backscatter Measurement Concept



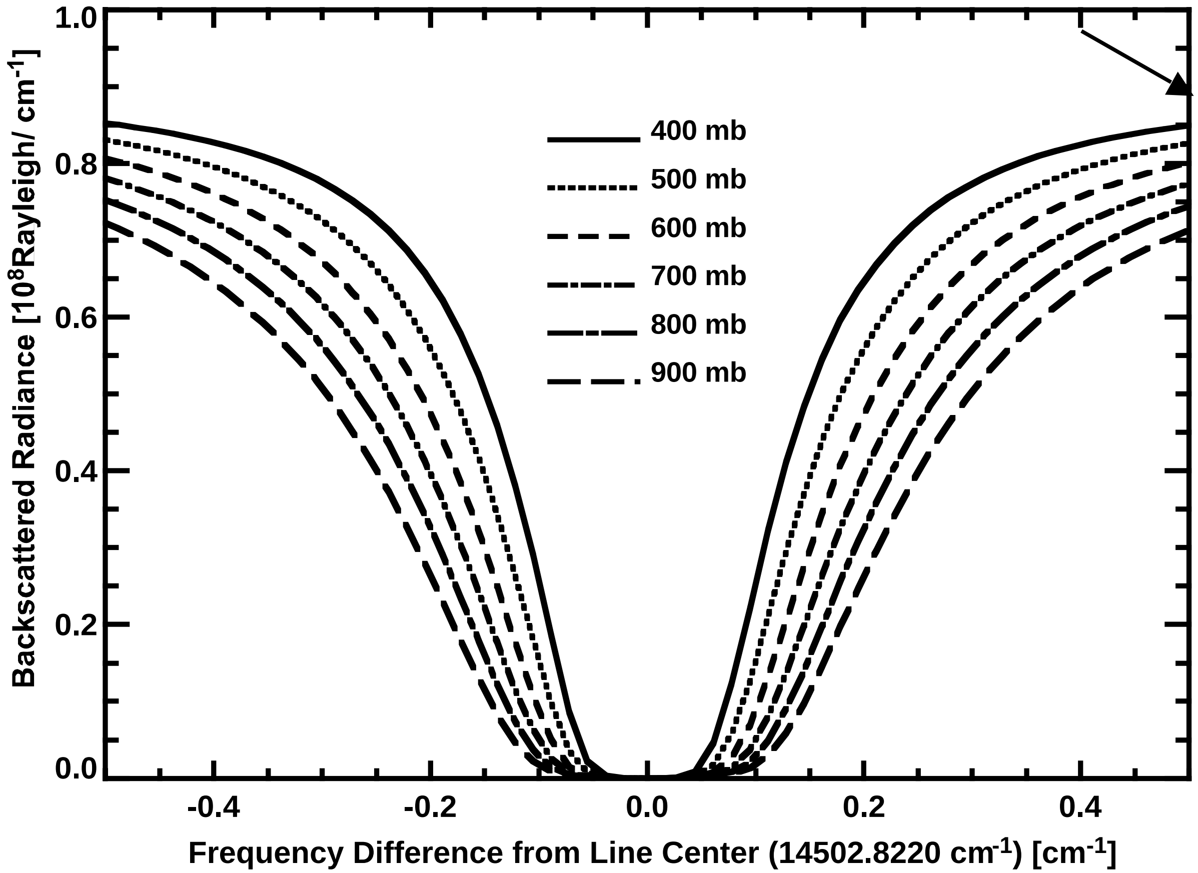
GIFS Remote Sensing: Absorption Line Shape Measurement Technique



- Line wings influenced by scene brightness without atmospheric absorption
- Line width is a proxy for average path pressure and total column density of the absorber of interest along absorption path
- Line depth related to total optical path of the absorber
- Width and depth are closely related

- The GIFS remote sensing technique takes advantage of the pressure broadening (and shift if useful) information embedded in the absorption line shapes to better determine the low-altitude atmospheric properties, including CO_2, CO column amounts and cloud properties.
- Potential applications:
    - CO_2 mixing ratio for study its sources and Sinks
    - Regional pollution monitoring: (e.g. CO)
    - Cloud property monitoring: cloud top pressure, cloud optical depth, and cloud fraction.

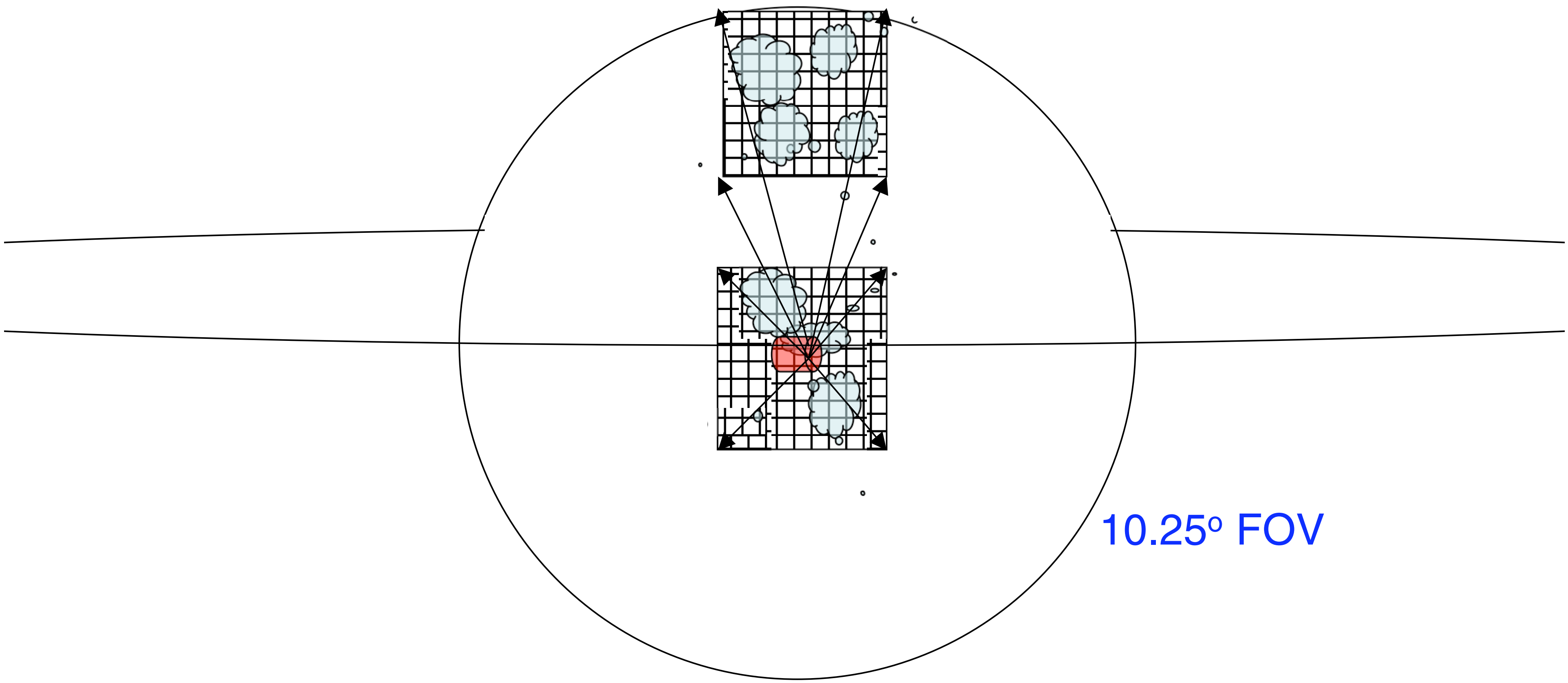
Simulated O_2 absorption line spectra



Cloud thickness: 100 mb
Cloud optical depth: 5

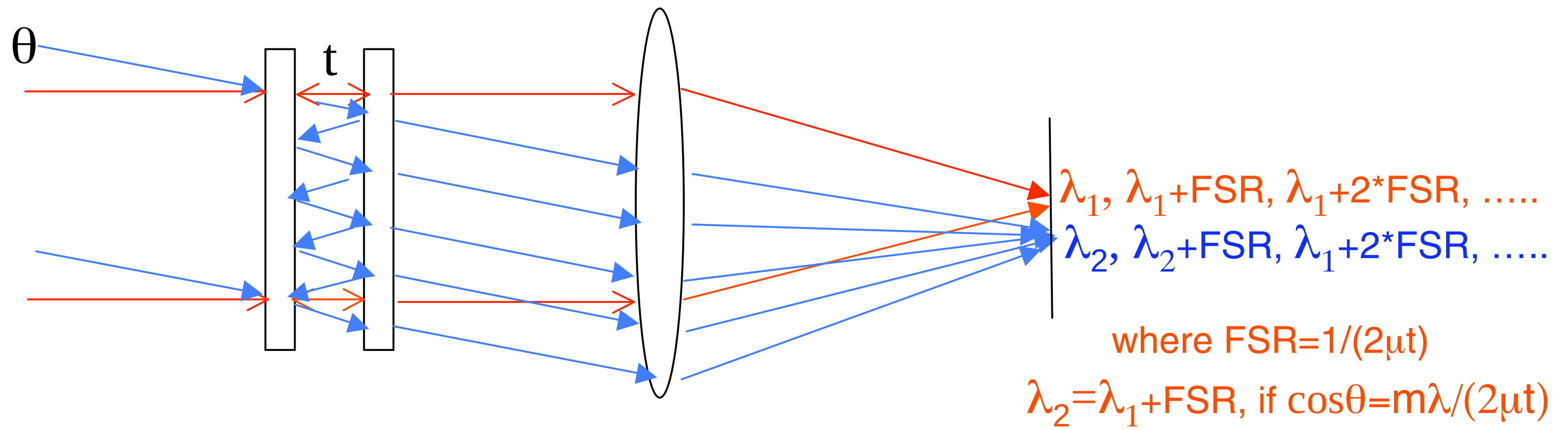
Why FPI?

Atmospheric Observations from a Geostationary Orbit

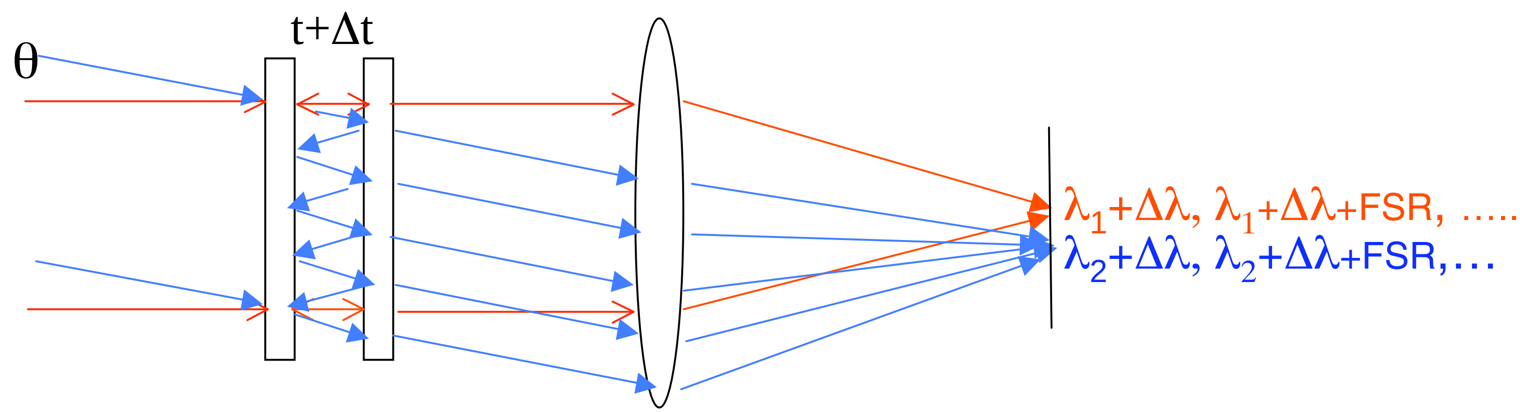


Spatial/Spectral Imaging

Fabry-Perot Interferometer: Background



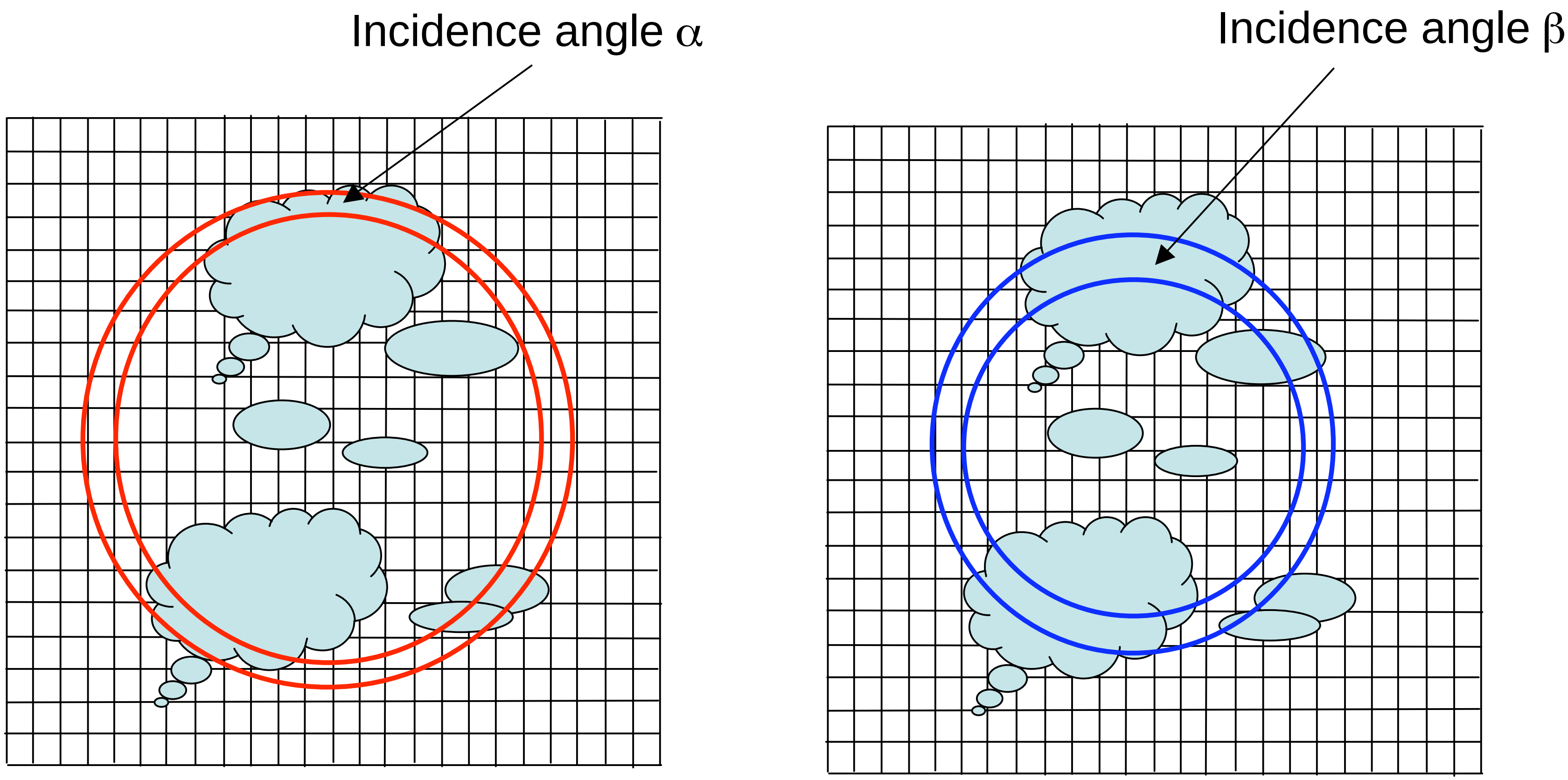
• At the focal plane, different frequencies are transmitted at different radial distance



• At the focal plane, resonant frequency changes as the etalon gap changes

Atmospheric Mapping from a Geostationary Orbit-1

FPI Imaging: pixel-to-pixel resonant frequency variation



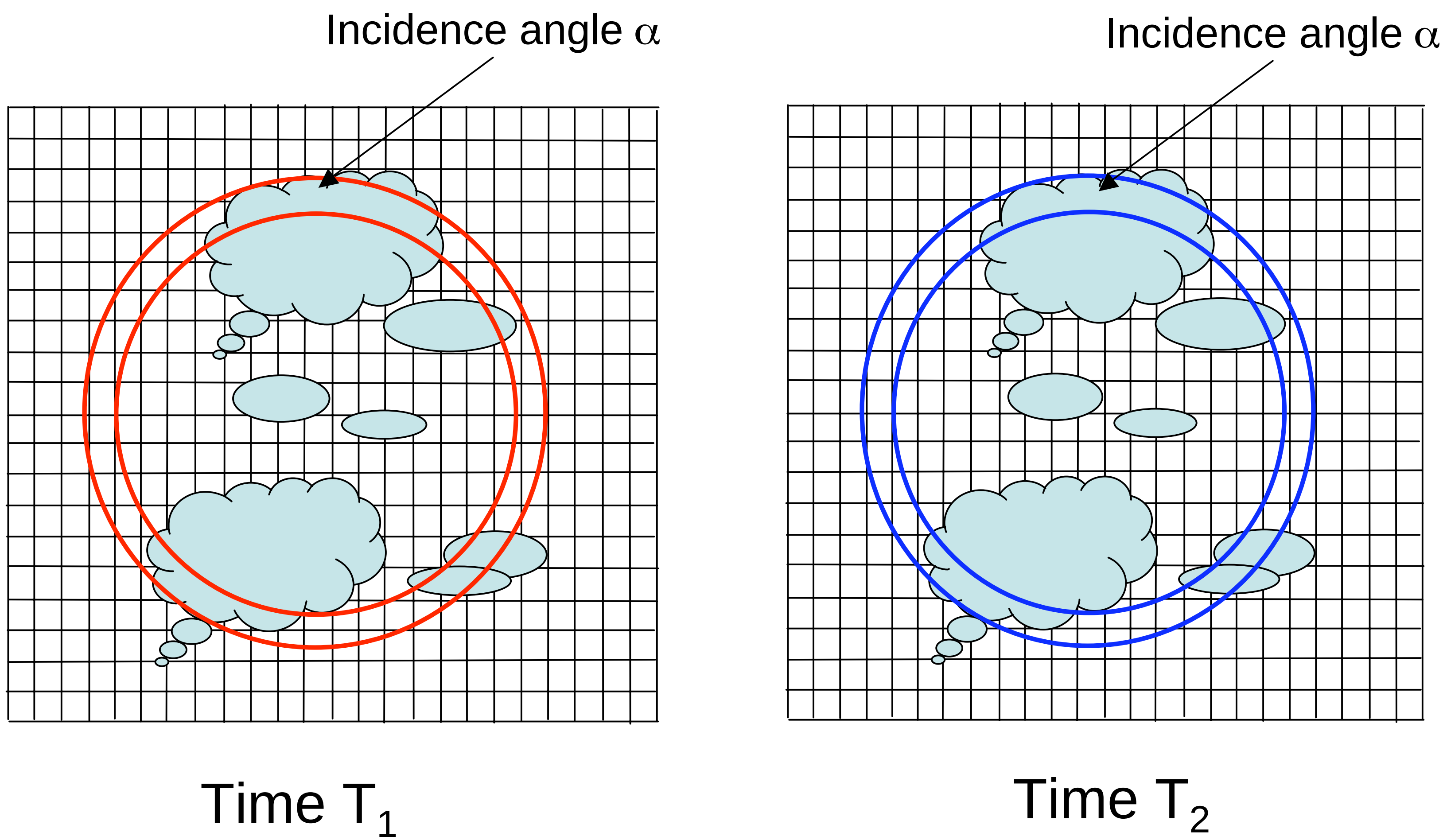
Time T_1

Time T_1

1^o incident angle (normal to etalon) => 2.2 cm^{-1} wavenumber shift (gap = 1.0 cm)

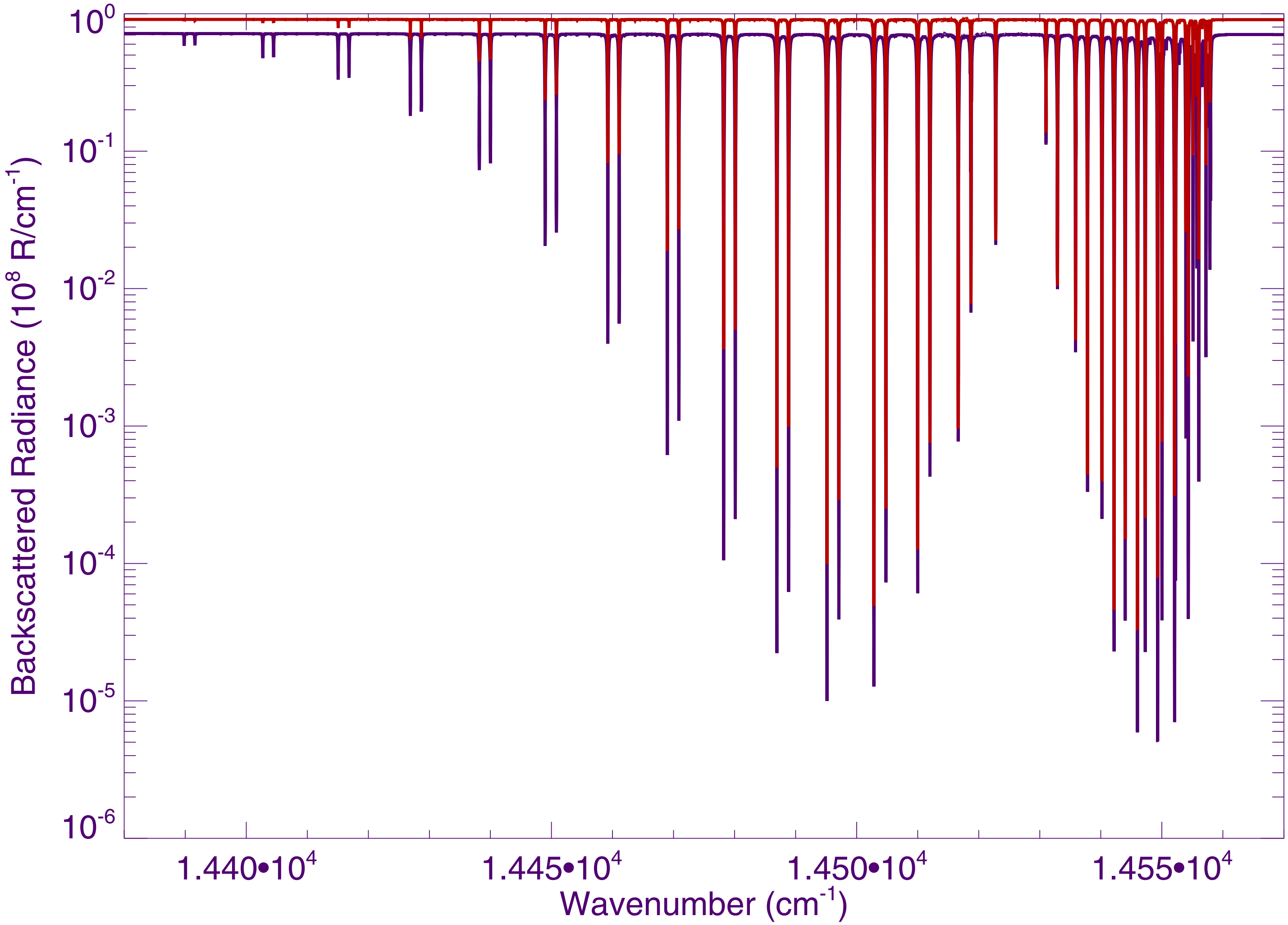
Atmospheric Mapping from Geostationary Orbit-2

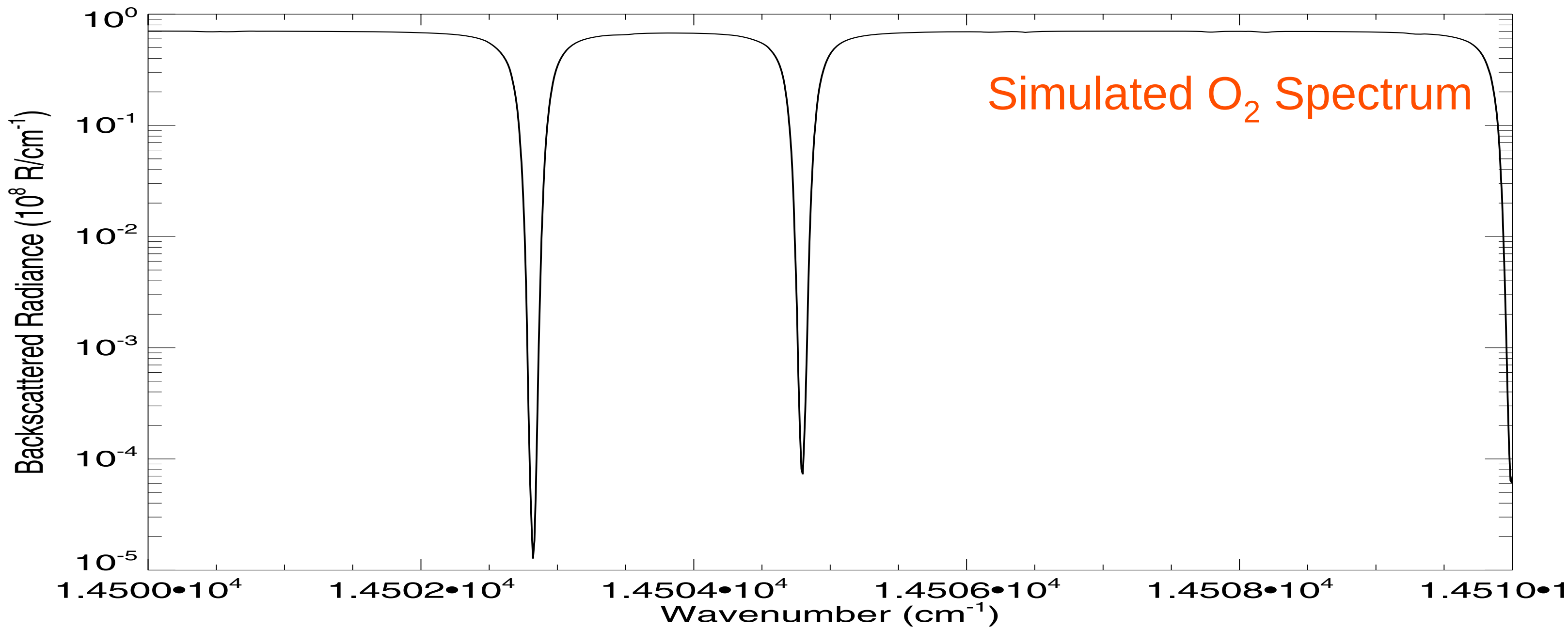
FPI Imaging: Gap (frequency) Scanning



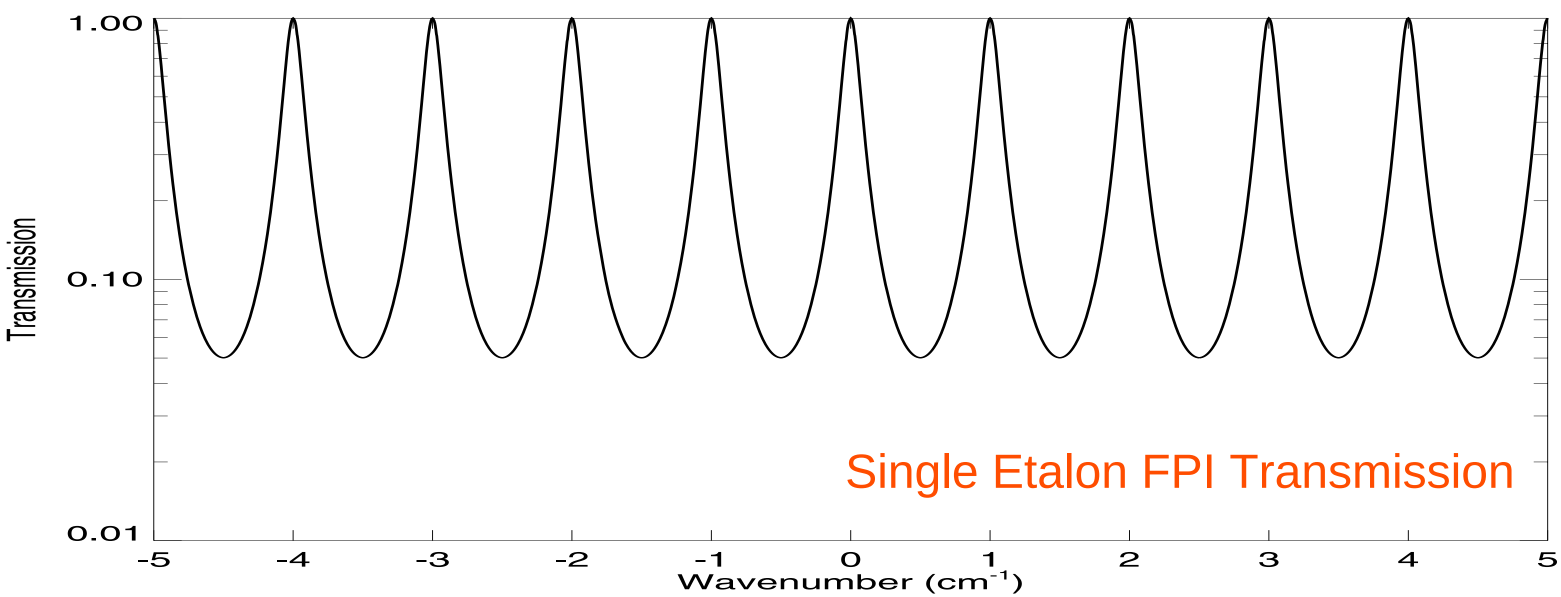
FPI gap changes => resonance frequency changes

Simulated O_2 absorption band spectra

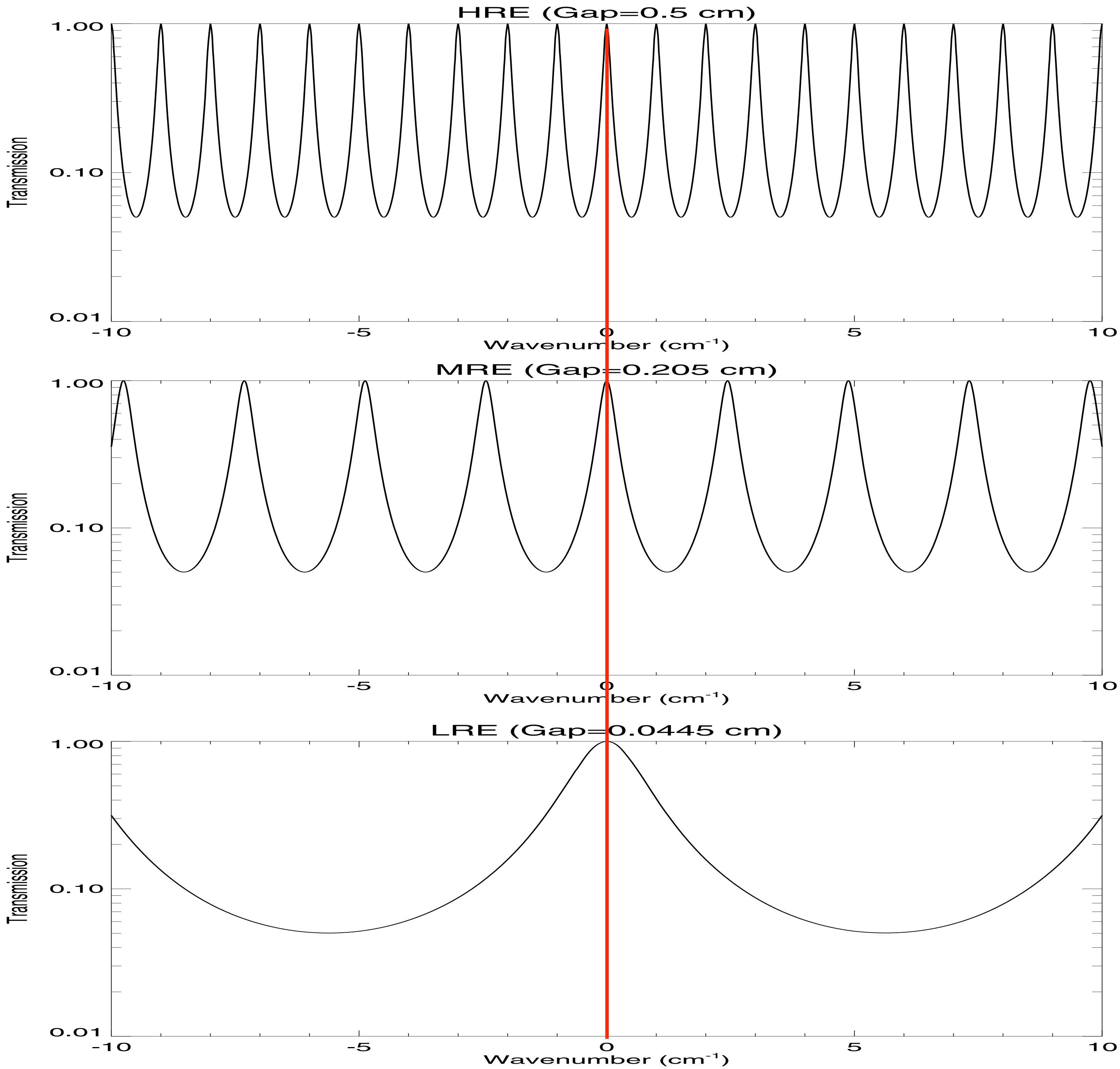




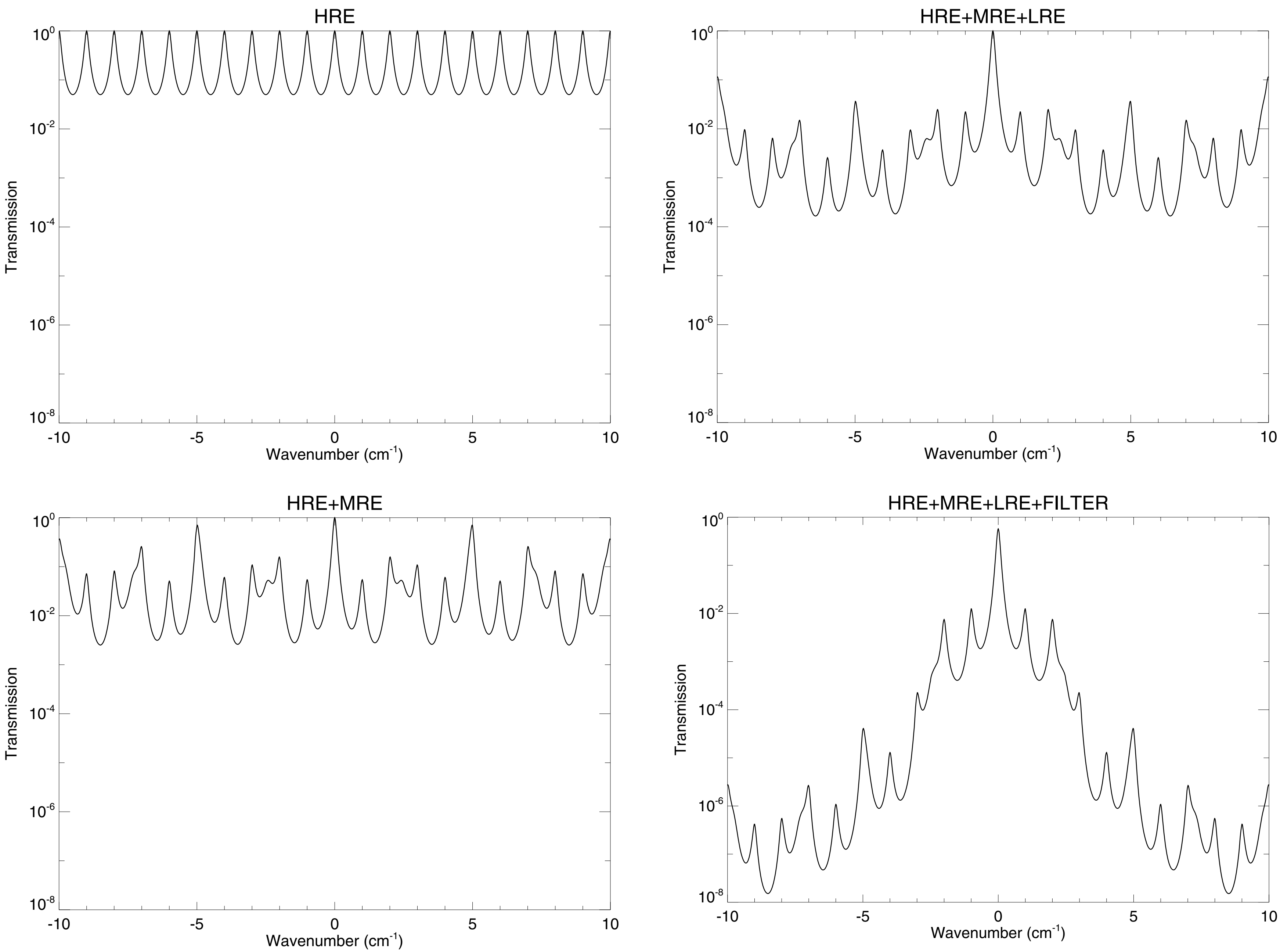
Simulated O2 Spectrum
Backscattered Radiance (10^8 R/cm^-1)
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
1.4500•10^4
1.4502•10^4
1.4504•10^4
1.4506•10^4
1.4508•10^4
1.4510•1
Wavenumber (cm^-1)

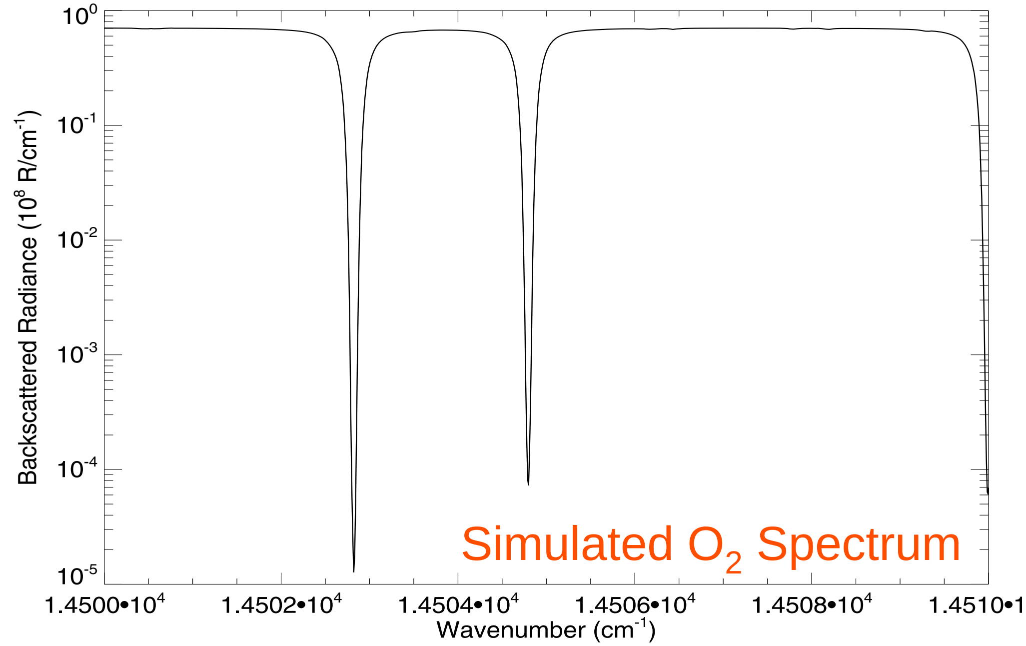


Single Etalon FPI Transmission
Transmission
1.00
0.10
0.01
-5
-4
-3
-2
-1
0
1
2
3
4
5
Wavenumber (cm^-1)

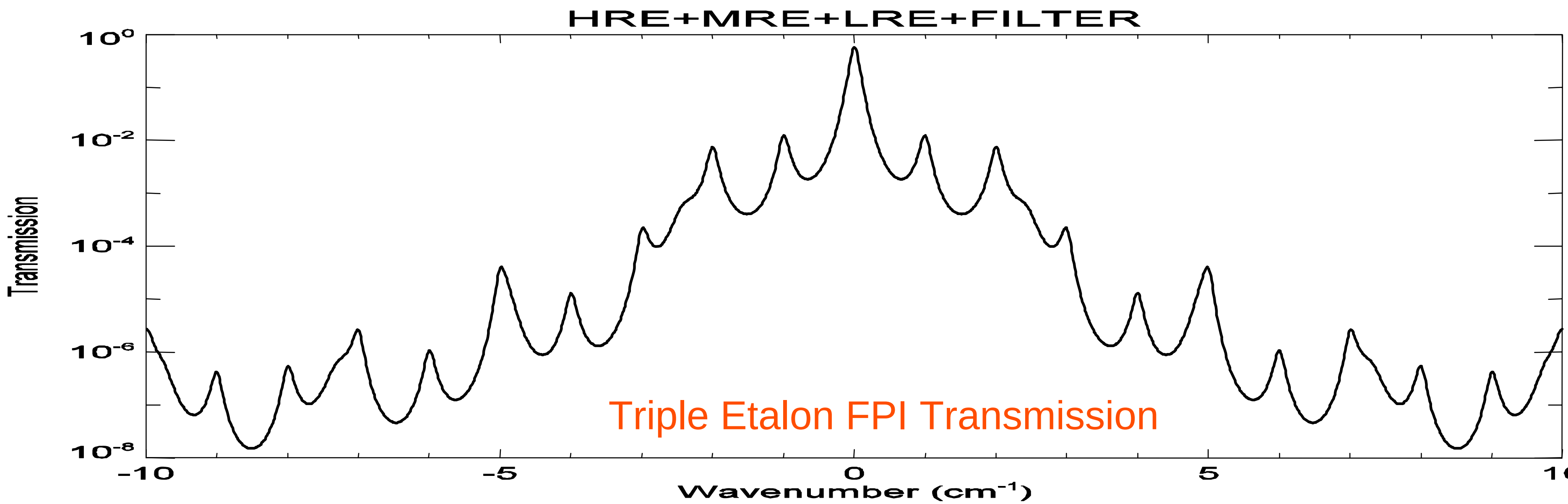


HRE (Gap=0.5 cm)
MRE (Gap=0.205 cm)
LRE (Gap=0.0445 cm)
Transmission
1.00
0.10
0.01
-10
-5
0
5
10
Wavenumber (cm-1)


HRE
HRE+MRE+LRE
HRE+MRE
HRE+MRE+LRE+FILTER
Transmission
Wavenumber (cm-1)
10^0
10^-2
10^-4
10^-6
10^-8
-10
-5
0
5
10

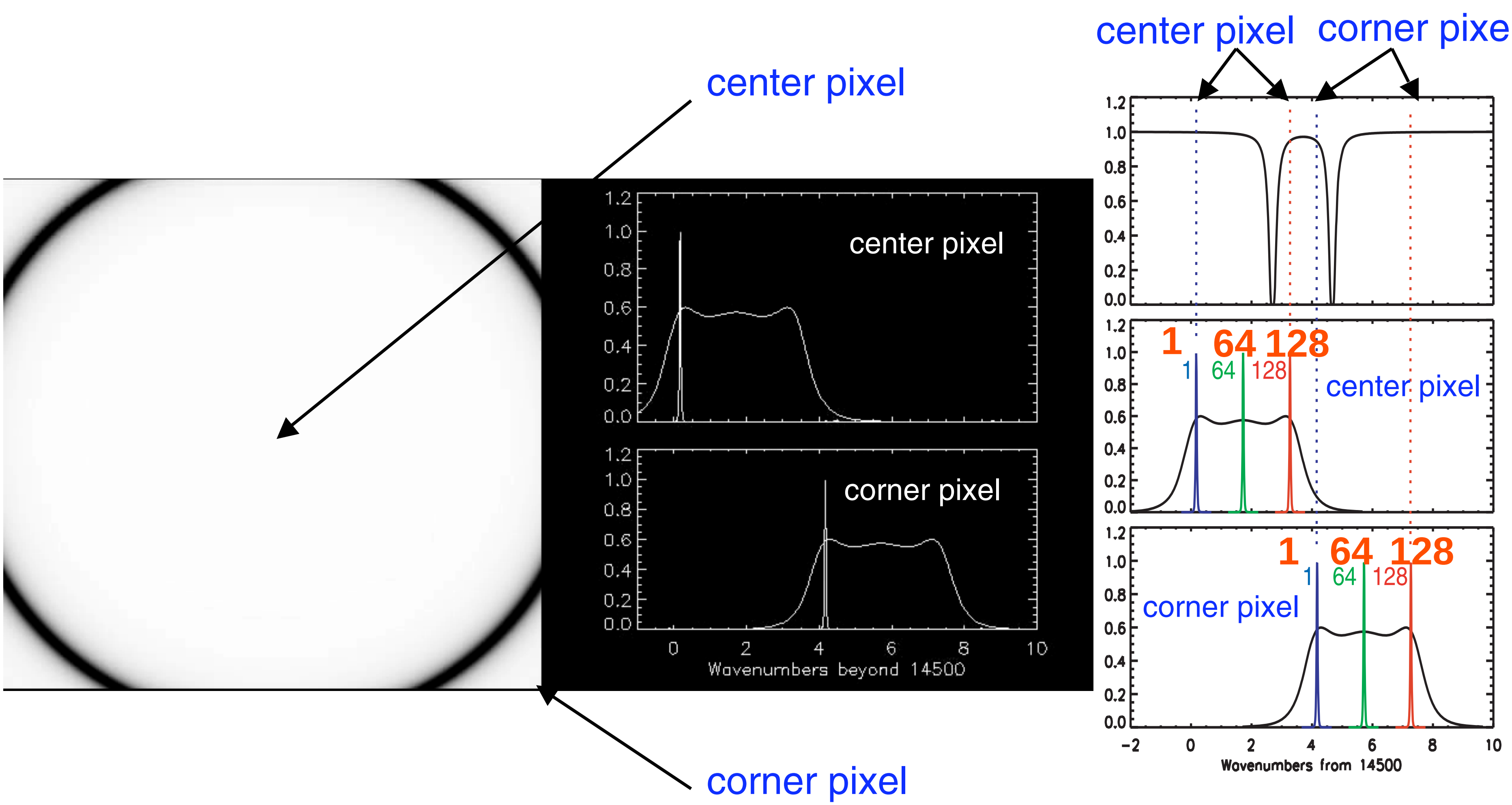


Simulated O_2 Spectrum
Backscattered Radiance (10^8 R/cm^{-1})
Wavenumber (cm^{-1})
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1.4500•10^4
1.4502•10^4
1.4504•10^4
1.4506•10^4
1.4508•10^4
1.4510•1

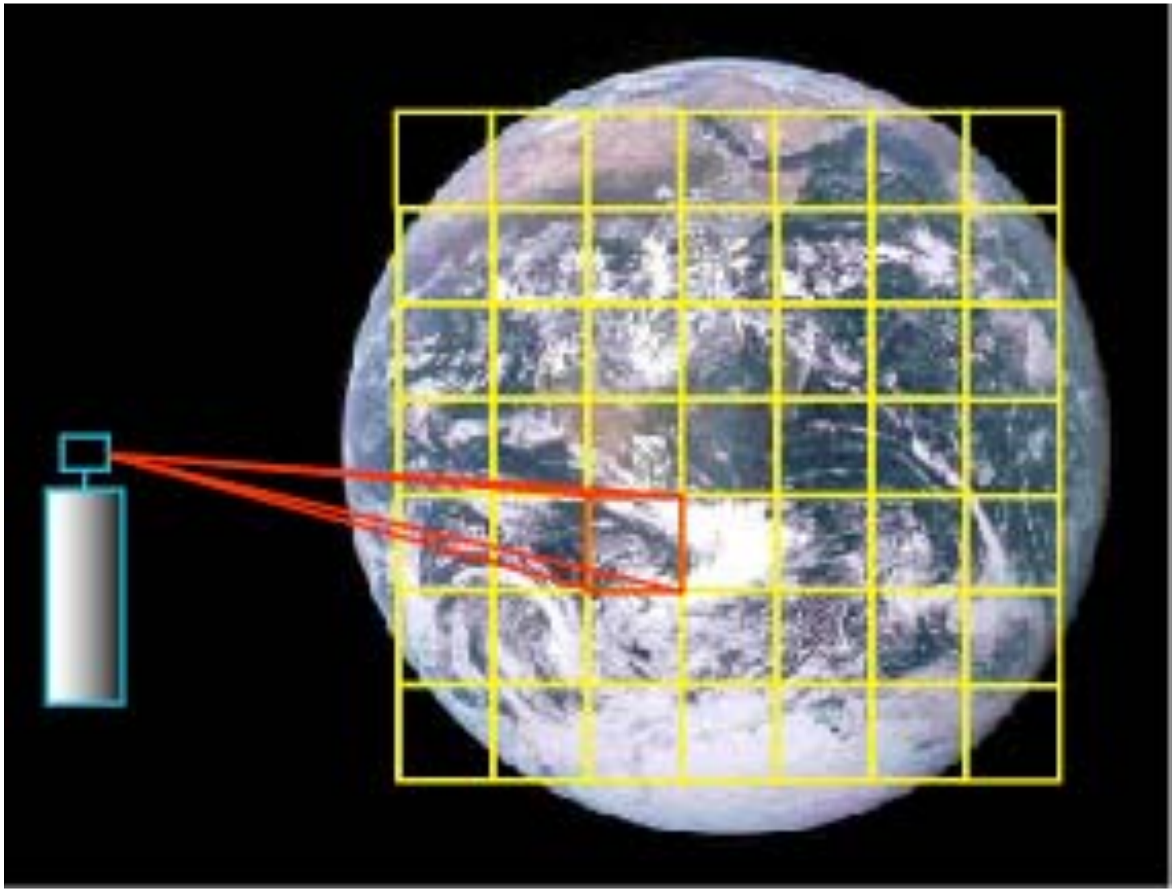


HRE+MRE+LRE+FILTER
Triple Etalon FPI Transmission
Transmission
Wavenumber (cm^{-1})
10^0
10^{-2}
10^{-4}
10^{-6}
10^{-8}
-10
-5
0
5
10

GIFS Spectral Scanning Animation

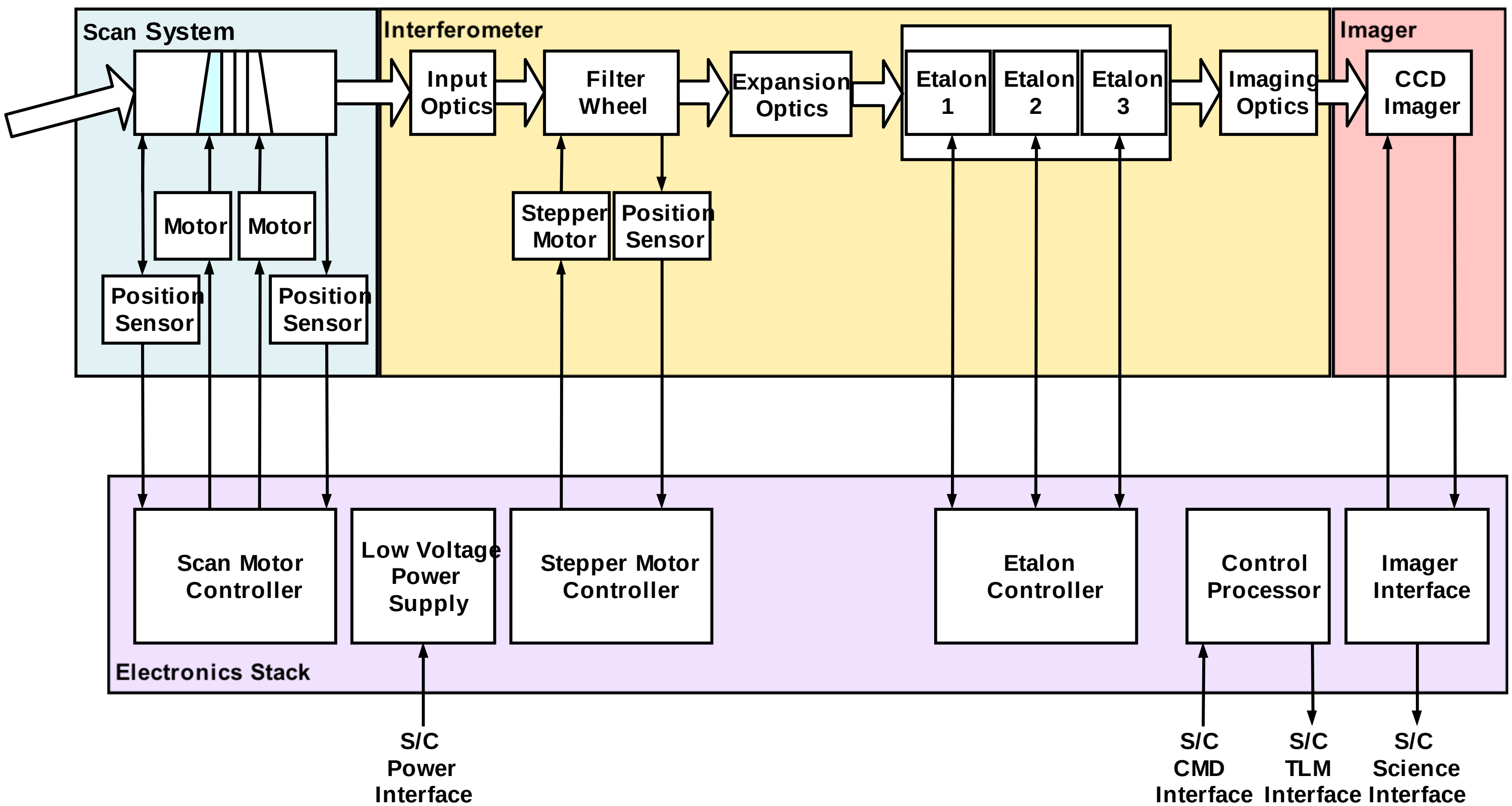


GIFS Measurement Mosaic



Images per mosaic: 25
image time: 2 min
spatial resolution: 4.4 km
or 1.1 km
revisit time: 1 hour
daytime only

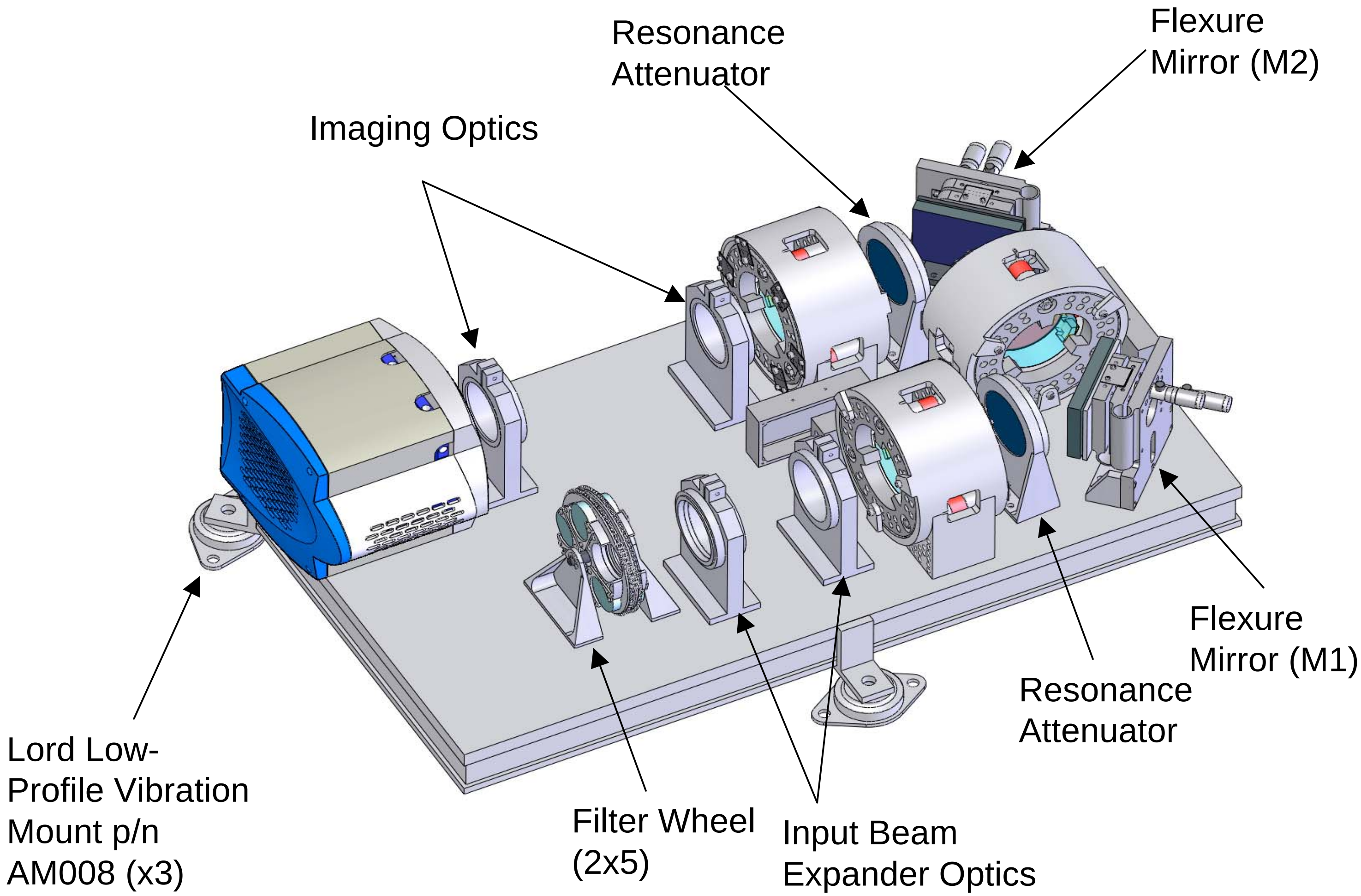
GIFS Instrument Block Diagram



Technically Challenging Areas

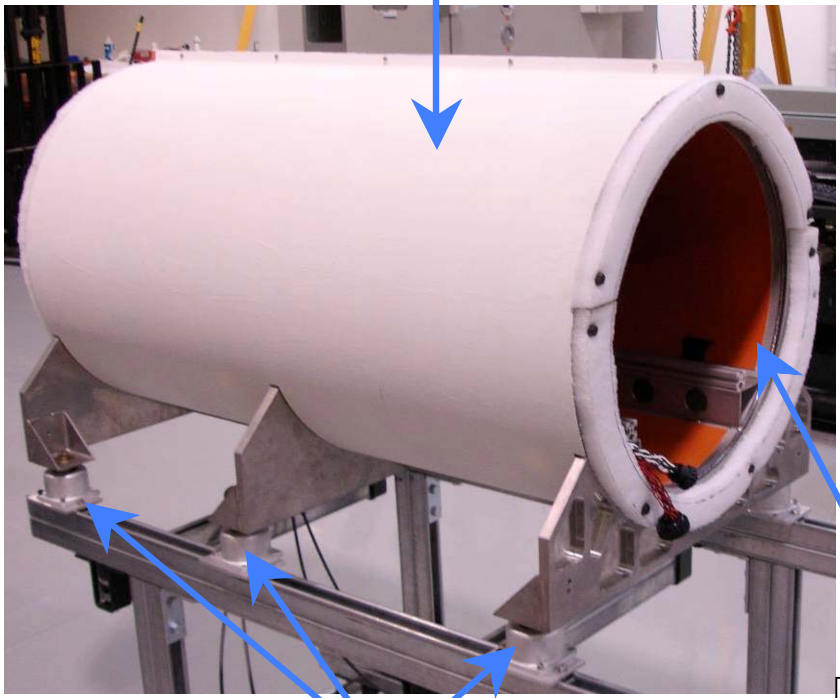
- Measurement Technique
  - Deriving cloud and surface pressure information from O_2 spectral line shapes have not be fully validated
  - GIFS testing flights will try to validate this technique using correlative measurements taken by LaRC spectrometer and lidar onboard the same aircraft
- Instrument design and performance
  - FPI instruments have been successfully flown in space (FPI/DE, HRDI/UARS, TIDI/TIMED)
  - GIFS is a next-generation imaging FPI instrument employing new technologies that have never been demonstrated:
    - To operate three etalons in tandem with high precision wavelength tuning in order to achieve the required wavelength resonance
    - To have an etalon plate and posts mechanical design that would survive launch vibrations
    - To operate triple etalon imaging FPI system successfully in a vibration environment (not critical under space environment)

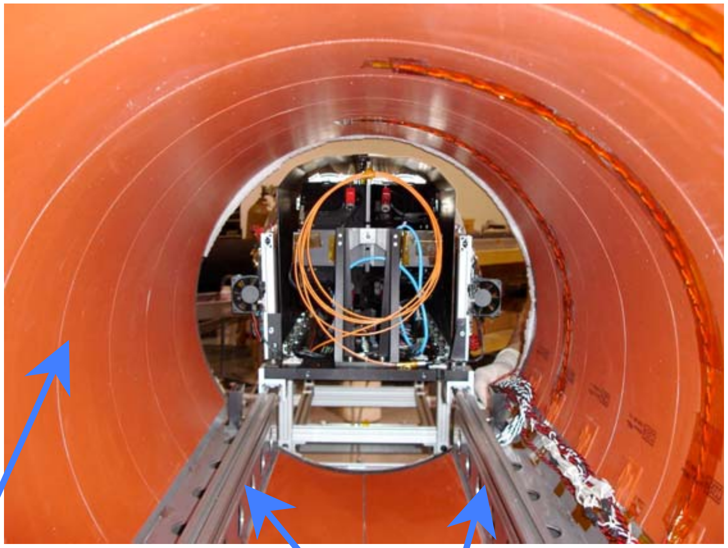
GIFS Interferometer Layout



Chamber From BalloonWinds

Thick insulator under shell of vessel provides added thermal stability.





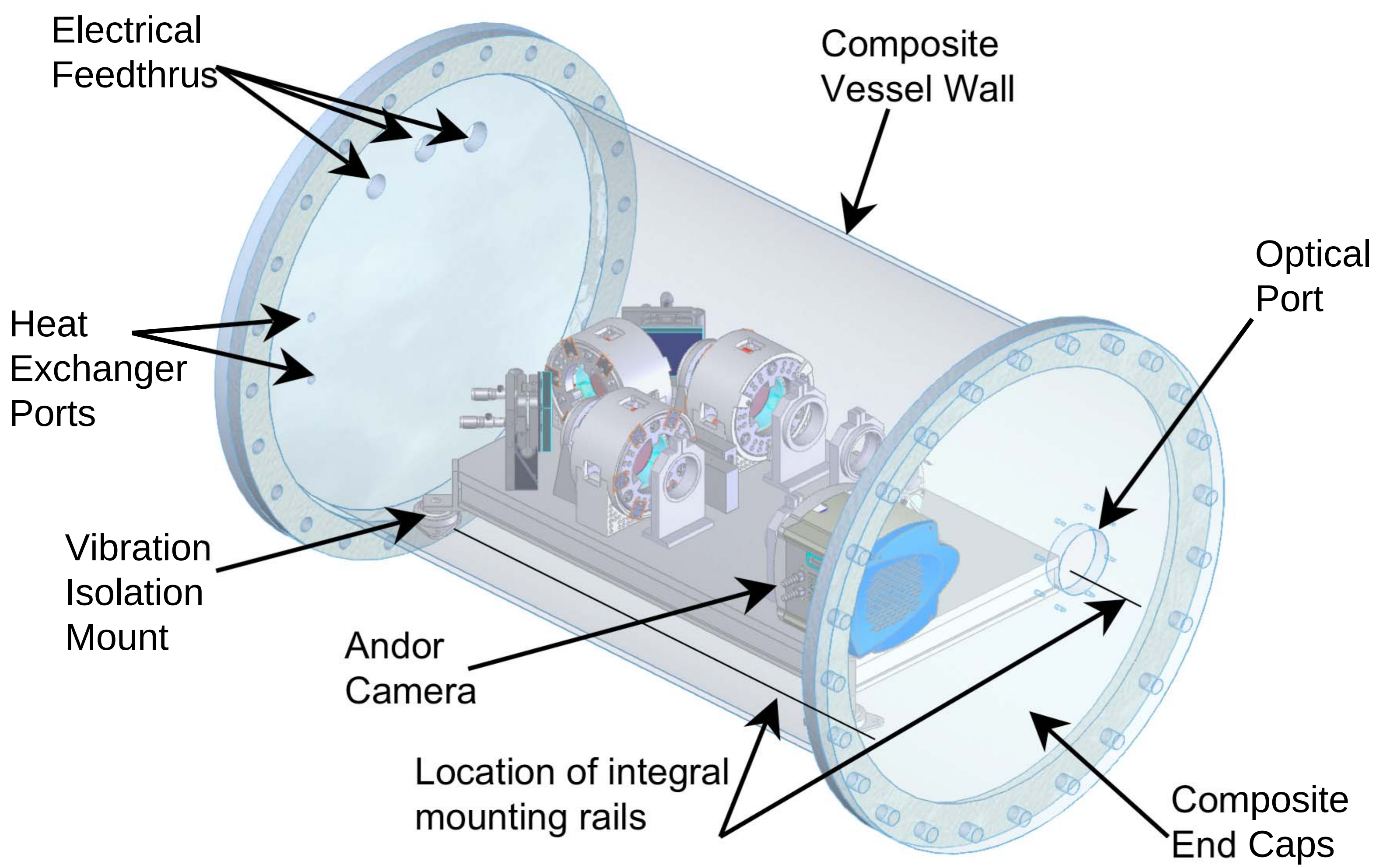
Vibration Isolation Mounts

Heater Pads Bonded to inner wall of cylinder

Guides for Equipment Plate

Thermal control will provide < 1 ^{0}C stability inside chamber!

Overview of Interferometer System



GIIP Test Flight Description

- Deploy 4 down-looking optical remote sensing instruments to measure cloud spatial distribution and optical properties
  - **GIFS IIP – Primary Instrument**
  - Langley Airborne A-band Spectrometer (LAABS)
  - High Spectral Resolution Lidar (HSRL)
  - Digital camera (for context)
- Platform
  - NASA Langley King Air B-200
  - 27000-28000 ft nominal flight altitude
  - Three flights
- Objectives
  - To test instrument performance of GIFS prototype
  - To validate GIFS remote sensing concept
  - To investigate new remote sensing strategies and retrieval techniques
- Deployment schedule: Around Nov. 2007

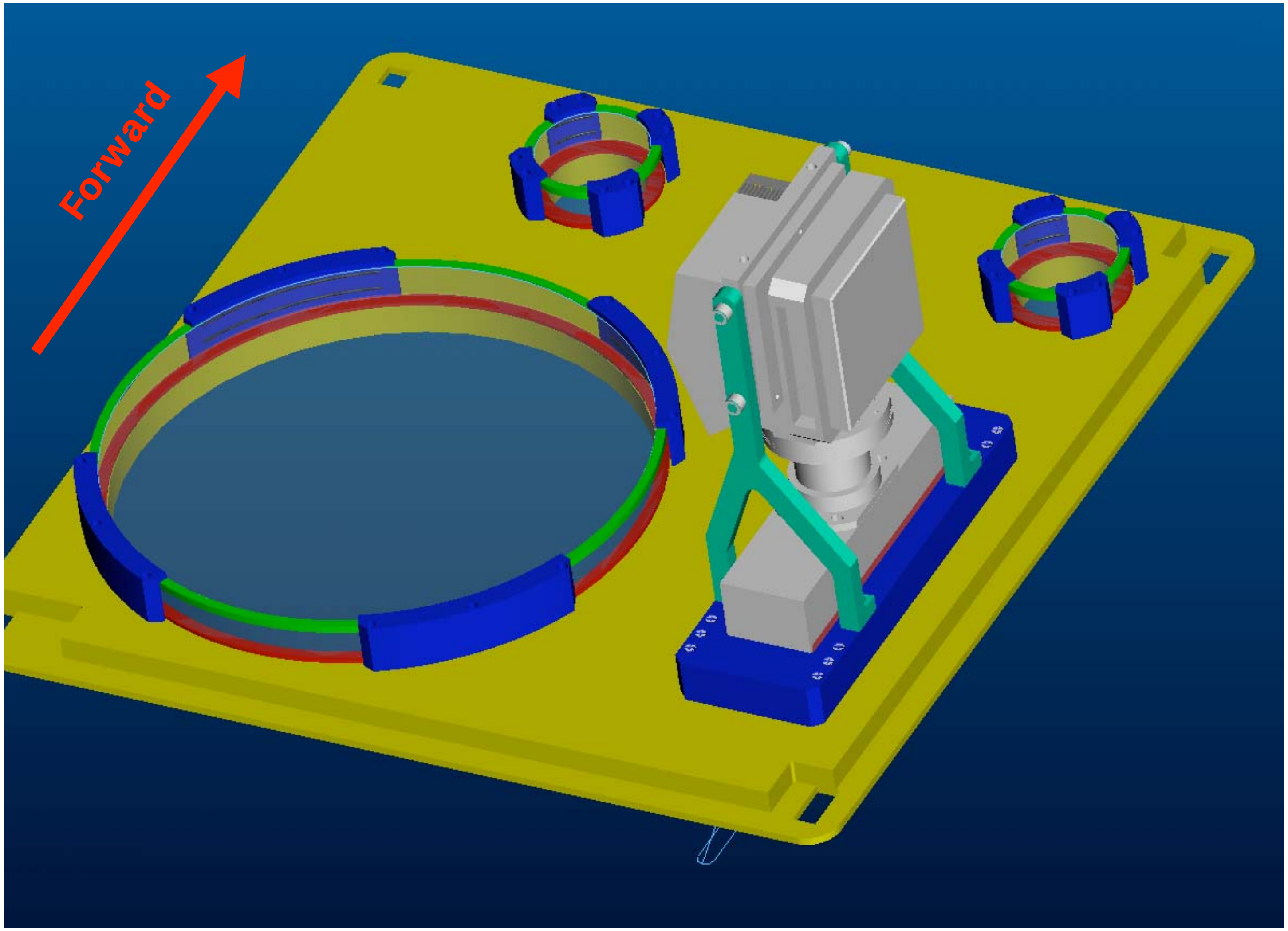
Backup Slides

LaRC King Air B200

Altitude	35,000 ft (10.7 km), maximum operating
Range	800 nmi (1,300 km) at sampling speed
Endurance	3.8 hr, maximum (with IFR reserve)
Speed	259 KIAS (133 m/s) cruise

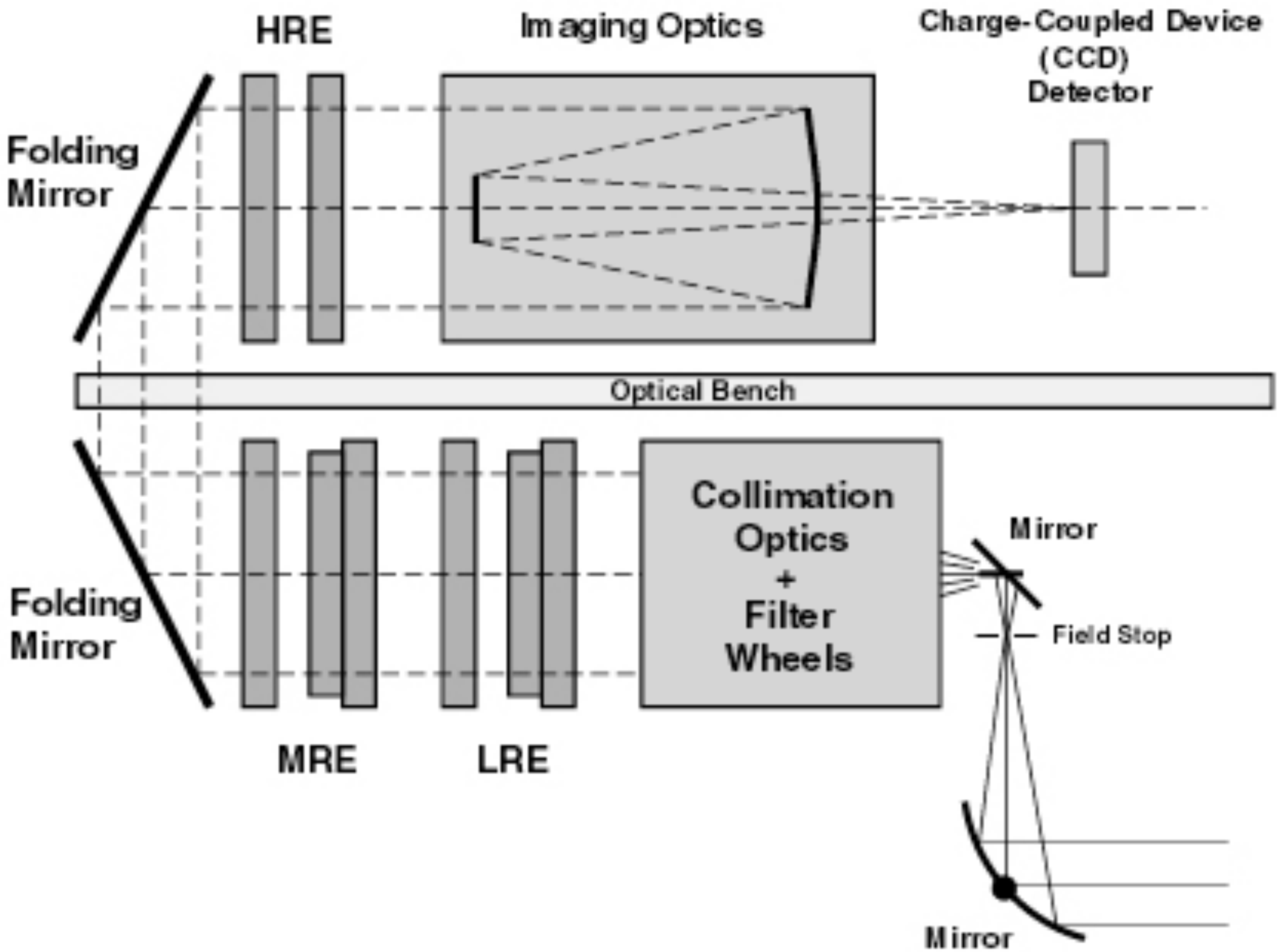
Payload	2500 lb (1,136 kg), maximum 500 lb (227 kg), with full fuel
Electrical Power	2 250A 30V DC generators, 3 1400VA, 400 Hz inverters supply 115V AC
Comm.	Iridium phone and modem

Nadir Ports for GIIP, LAABS, HSRL, and Camera



- **Maximum clear aperture of optical port is approximately 24 in. by 24 in.**
- **Window material for large aperture port is typically BK-7 glass.**

GIFS Instrument Optical Schematics



GIFS Objectives

- The GIFS remote sensing technique takes advantage of the pressure broadening (and shift if useful) information embedded in the absorption line shapes to better determine the low-altitude atmospheric properties, including CO_2, CO column amounts and cloud properties.
  - Potential applications:
    - CO_2 mixing ratio for study its sources and Sinks
    - Regional pollution monitoring: (e.g. CO)
    - Cloud property monitoring: cloud top pressure, cloud optical depth, and cloud fraction.
- A prototype GIFS instrument is being developed under the support of NASA Instrument Incubator Program (IIP) office
  - To investigate all aspects of the GIFS flight instrument design, from a detailed instrument requirements analysis to the construction, characterization, and aircraft testing of a GIFS prototype instrument, with the goal of verifying the performance and raise the TRL levels of critical and technically challenging subsystems
    - Spectral tunability
    - Imaging capability

Instrument Parameter	Specification
Operating Wavelength	689.6 nm
Field of View of Instrument	4.324^0
Full Angle Through Etalons	2.264^0
Detector Format	512 x 512
Pixel Size of Detector	16 μm
Divergence through Etalons	77μ rad / pixel
CCD Binning	4 x 4
Filter Clear Aperture	2.618 cm (~1”)
Filter Index	1.91
Spatial Resolution (w/ binning)	8.257 m
Full imaged scene	1.057 km^2
F/# of Imaging System	4.147
Required signal at CCD	>20,000 e-/binned pixel
Filter Bandwidth (FWHM)	≤ 8 cm^{-1} (or 0.38 nm)

Motivations

"Clouds are essential elements of the climate system because of their controlling impact on the earth's radiation balance, atmospheric radiative heating or cooling, and surface radiation."

"NASA selected four high-priority research topics……… These for research foci are (1) the controlling role of water vapor and clouds in radiation transfer and the earth's radiant energy balance, (2)……."

NASA Research Strategy for Earth System Science: Climate Component
Ghassem Asrar, Jack A. Kaye, and Pierre Morel
Office of Earth Science, NASA
Bulletin of the American Meteorological Society, July 2001

Cloud Properties Measurements Considerations

- Cloud Properties:
  - cloud top pressure (height)
  - cloud bottom pressure (height)
  - cloud optical depth
  - cloud fraction, and
  - cloud frequency
- Measurement requirements:
  - accuracy
  - spatial resolution
  - temporal resolution
  - revisit time

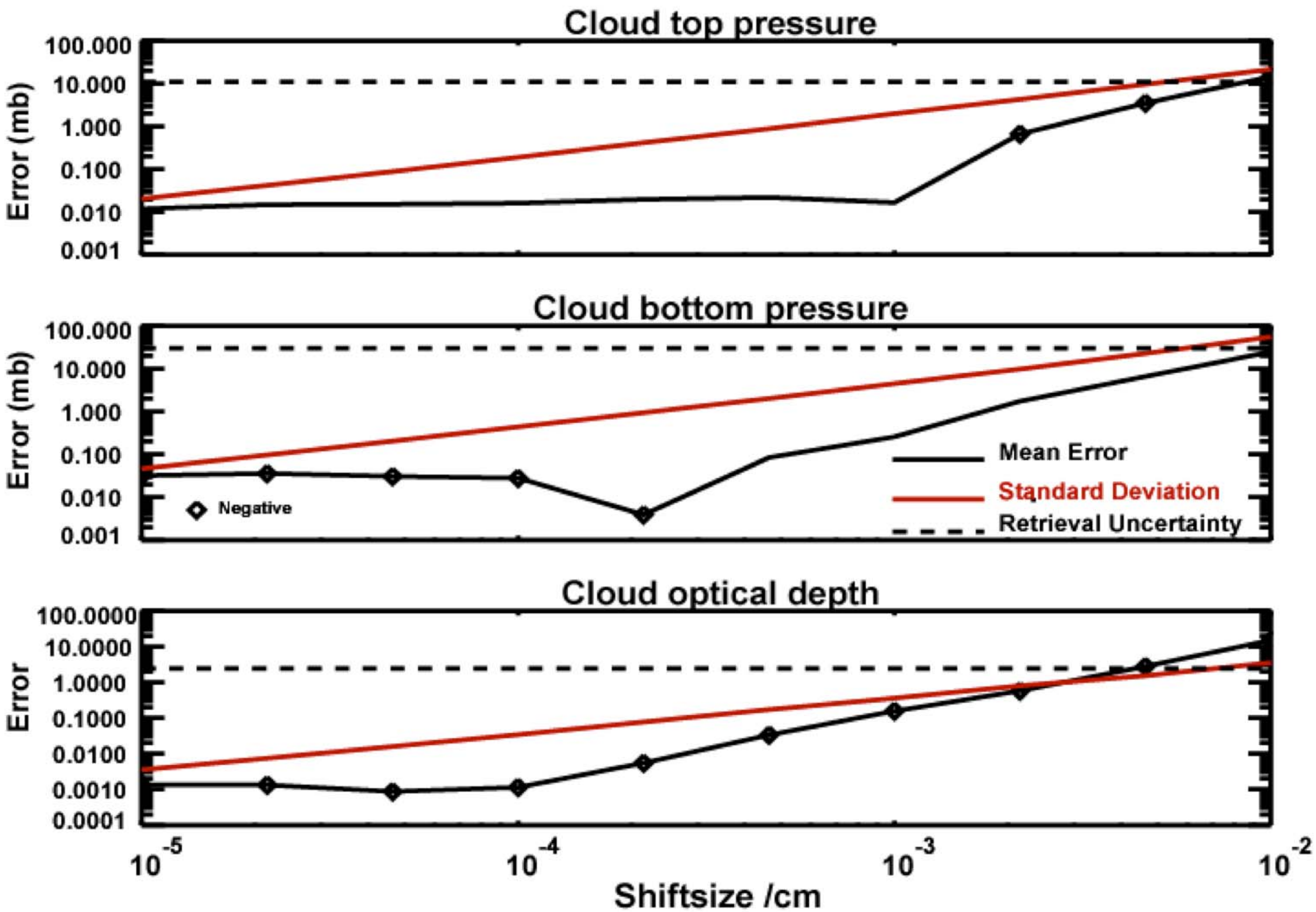
Measurement Uncertainties (top:800 mb, bottom:900 mb) at 4.4 km resolution

Cloud optical depth	Optical depth uncertainty	Cloud top pressure uncertainty (mb)	Cloud height uncertainty (m)
1	0.009	24	240
5	0.08	12	126
50	6	8	85

Measurement Uncertainties (top: 500 mb, bottom: 600 mb) at 4.4 km resolution

Cloud optical depth	Optical depth uncertainty	Cloud top pressure uncertainty (mb)	Cloud top height Uncertainty (m)
1	0.006	15	220
5	0.06	8	116
50	4	5	79

Optimization for Aircraft Stability



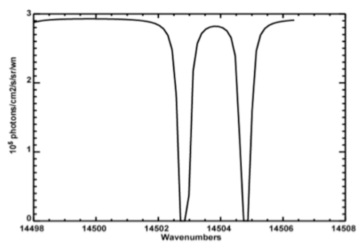
Common Specifications	Value
Clear Aperture	5.0 cm
Reflectivity	85 ± 2%
Coating Wavelength	600-800 nm
Plate Flatness	λ/150 @ 633 nm
Finesse	>15
Spectral Step Resolution	<0.015 cm^{-1}
Gap Step Resolution	<0.5 nm
Dynamic Range	3-5 μm
Tolerance on Gap Spacing	± 0.002 cm
Repeatability	< 10^{-3} cm^{-1}

	HRE	MRE	LRE
FSR	1.5 cm^{-1}	3.32 cm^{-1}	7.102 cm^{-1}
Gap Spacing	0.333	0.1506 cm	0.0704 cm
# Orders Imaged	1.88	0.852	0.398

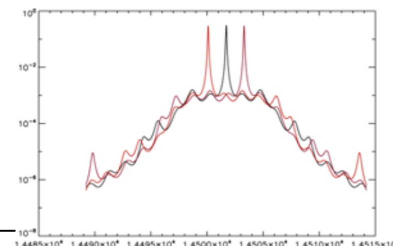
GIFS Design Strategy

atmosphere and cloud properties

Radiance Simulator



radiance at sensor*



Instrument Simulator

instrument parameters

simulated measurement*

Sensitivity Analysis

Iteration

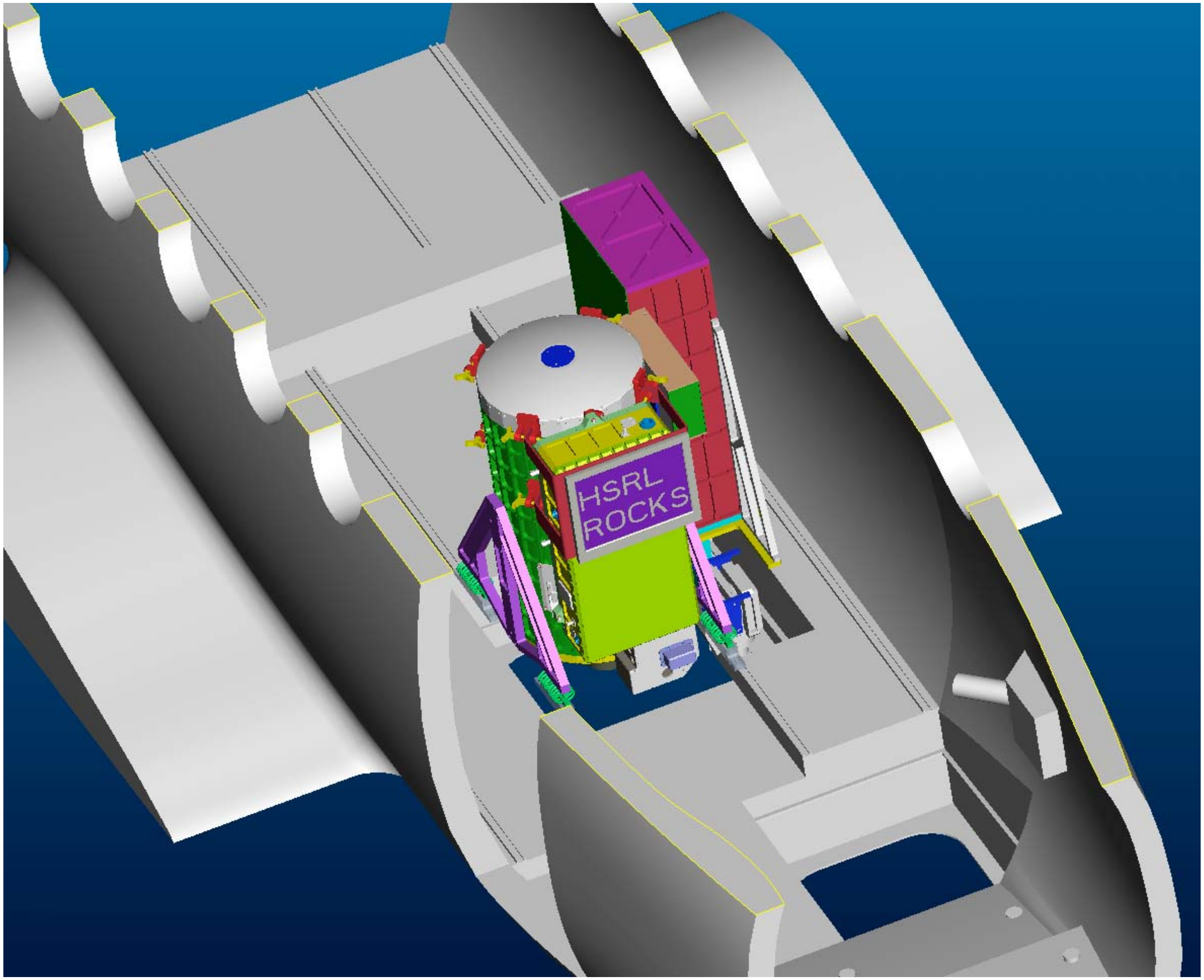
estimated retrieval sensitivity

Optimize Retrieval Quantities

- **Cloud Height**
- **Cloud Optical depth**

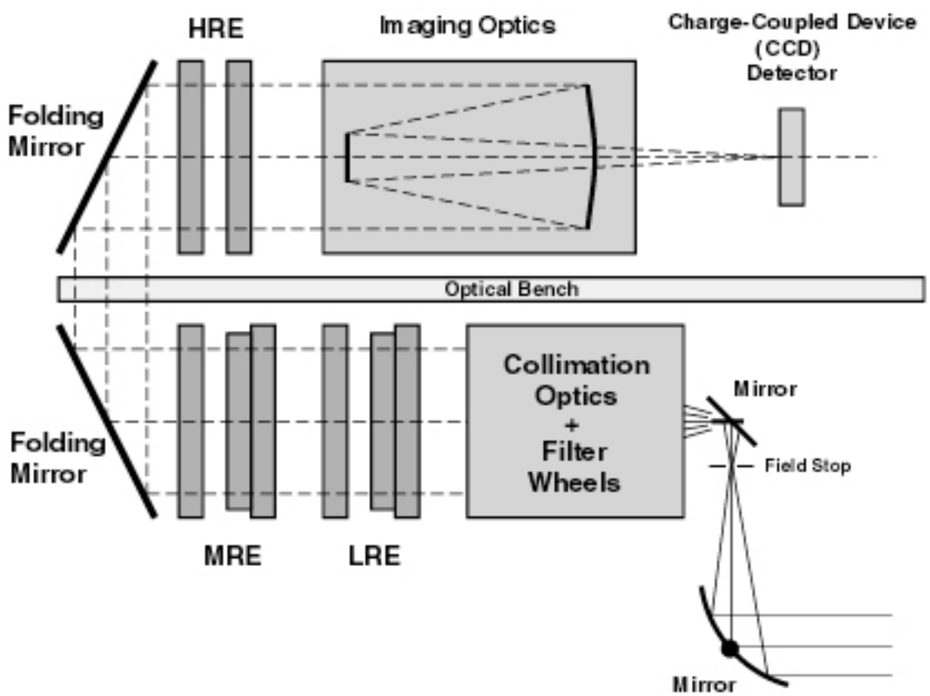
***Includes derivatives**

Instrument Configuration in B-200



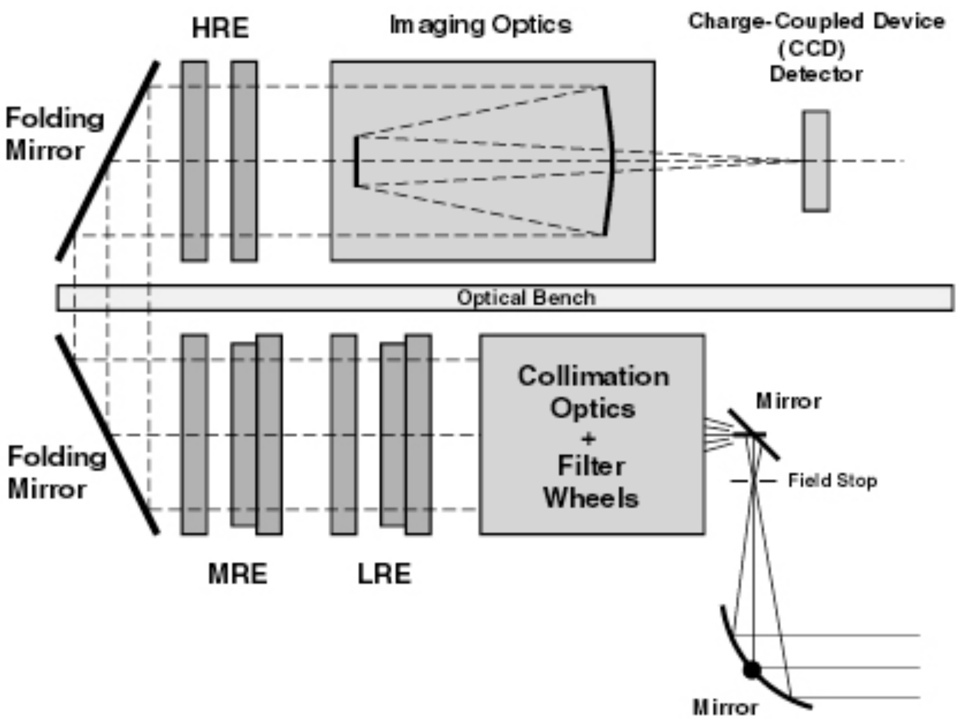
- **Note: Two ports shown are standard mods to the B200 aircraft.**
- **The LaRC B200 is outfitted with the forward port only.**
- **The GIIP instrument will replace HSRL instrument shown here**

GIFS Instrument Description



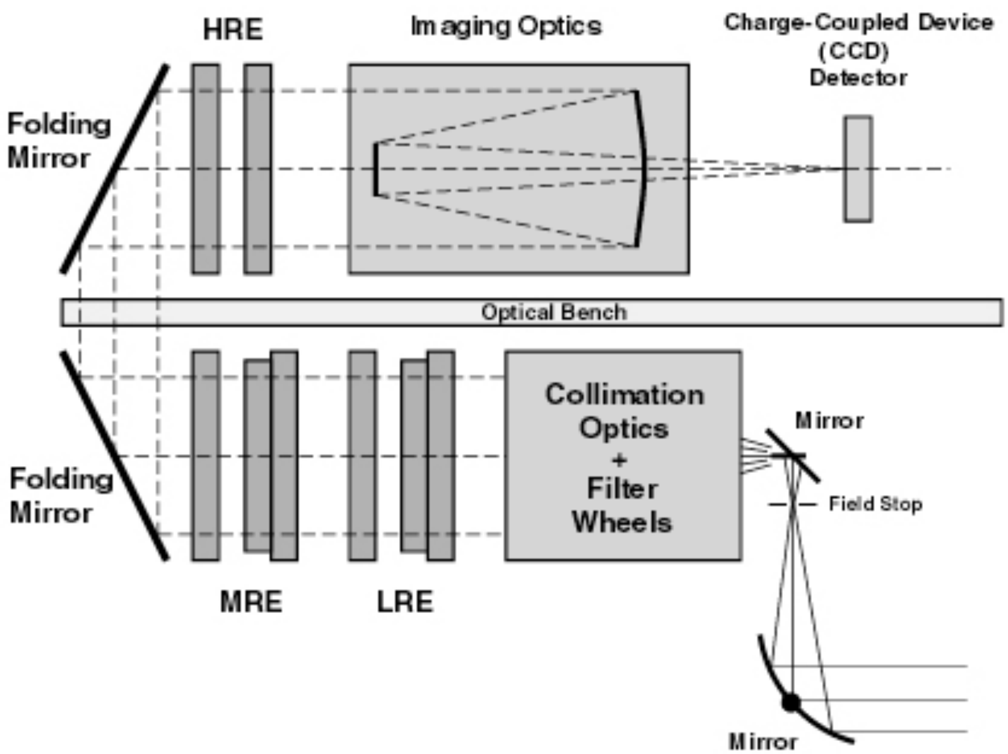
	Parameters	Engineering Driving Requirement	Value
Telescope			
	Aperture	throughput	79 mm
	Field of view	spatial coverage	3.6°
Filter			
	Type	line transmission	3 cavity
	Peak transmission	signal to noise	>0.6
	Spectral width	off-band rejection	0.4 cm^{-1} FWHM
	Effective index	spectral shift	2

GIFS Instrument Description



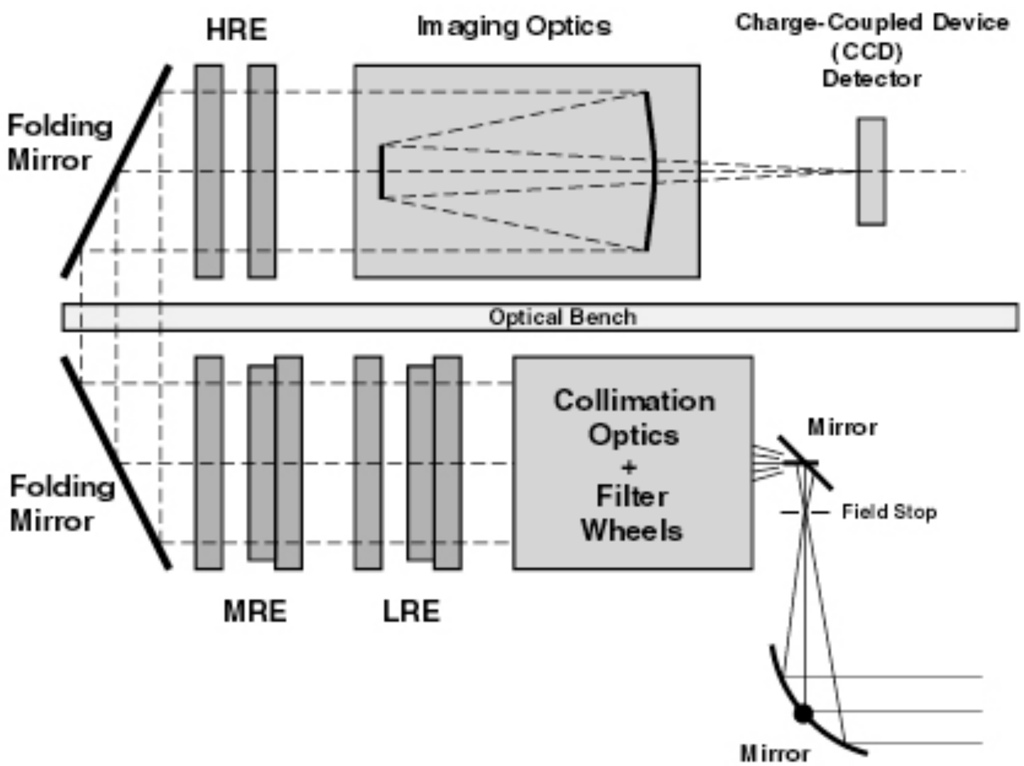
Interferometer		
# of etalons	off-band rejection	3
Clear aperture	sensitivity	150 mm
Gap thicknesses	spectral resolution off-band rejection	0.5 cm (H) 0.205 cm (M) 0.0445 cm (L)
Free Spectral Range (FSR)	spectral resolution off-band rejection	1.0 cm^{-1} (H) 2.44 cm^{-1} (M) 11.24 cm^{-1} (L)
Reflectivities	same as FSR	0.90
System finesse	same as FSR	20
Spectral resolution	retrieval precision	0.05 cm^{-1}

GIFS Instrument Description



Detector		
Array size	spatial resolution	1024 x 1024 (or 512x512)
Pixel pitch	angular resolution	13 mm
Read noise	signal to noise	<10 el /read
QE	signal to noise	0.88
Integration time	signal to noise	1 sec

GIFS Instrument Description



System		
Pixel sensitivity	signal to noise	$1.6x10^{-4}$ e/R/cm^{-1}/sec
Pixel resolution	footprint size	0.0035° or 1.1 km
Acquisition time	signal to noise	1 second